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(54) Title: METHOD OF EVALUATING A REACTION FOR THERMAL RUNAWAY

(57) Abstract

Thermal runaway of a reaction in a shell and tube reactor occurs when the rate of reaction exceeds the rate of heat removal and should be avoided. The present invention provides a method for evaluating a reaction within a shell and tube reactor for signs of thermal runaway. The method includes the steps of equipping a plurality of reactor tubes with a thermocouple; restricting the flow of reactants through selected reactor tubes which contain a thermocouple; operating the process at desired reaction conditions; determining a temperature profile for each reactor tube containing a thermocouple; comparing the differences between the temperature profiles for the reactor tubes into which the flow of reactants is restricted and the temperature profiles for the reactor tubes into which the flow of reactants is not restricted; and correlating the differences between the temperature profiles with signs of thermal runaway. The reaction conditions could then be adjusted in response to signs of thermal runaway.

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METHOD OF EVALUATING A REACTION FOR THERMAL RUNAWAY

BACKGROUND OF THE INVENTION

Field Of The Invention

The present invention is directed to a method of evaluating a reaction in a shell and tube reactor for signs of thermal runaway and an associated apparatus for reducing the flow of reactants into a reactor tube inside of a shell and tube reactor.

The Related Art

Shell and tube reactors are useful in many chemical processes. They are particularly useful in the vapor-phase production of vinyl acetate, ethylene oxide, and acrylic acid.

Shell and tube reactors are commonly comprised of a plurality of tubes spaced apart from one another inside the shell of the reactor. The tubes are usually loaded with a catalyst. In many cases, the catalyst is loaded onto a support which is often in the form of pellets. The support bearing the catalyst is loaded into each of the reaction tubes. In the case of the production of vinyl acetate ("VA"), the reactants, acetic acid, ethylene, and oxygen, are maintained in the vapor phase and passed through each tube over the catalyst. Thus, the reaction takes place within the tubes.

Each of the reactions that produces vinyl acetate, ethylene oxide, and acrylic acid is exothermic. Accordingly, a cooling fluid, such as water in the case of vinyl acetate, is circulated inside the shell around each individual tube for heat transfer. Substantial heat is generated by the reaction, thus the need for cooling for heat dissipation.

Because each reaction is exothermic, control of each of these processes requires careful evaluation of the temperatures of the reaction within the reaction tubes. An increase in temperature is one indication that the catalyst may be aging or that the reaction is becoming uncontrolled.

With respect to the vinyl acetate process, as the catalyst ages, the temperature of the reaction will generally increase. At a certain point, carbon dioxide ("CO_2") is produced in increasing amounts. The production of CO_2 is also an exothermic reaction which has a higher heat of reaction than the formation of VA, thus generating even more heat. Indeed, the cumulative heat of reaction begins to increase as the CO_2 production increases. As previously stated, heat generated in the reaction tubes is transferred to the water or other fluid surrounding those tubes for dissipation. When the heat of reaction exceeds the heat removal capability of the reactor, a dangerous condition known as thermal runaway or "runaway reaction" occurs thus causing hot

spots. In a thermal runaway, there is also an increase in the production of reaction byproducts, primarily CO_2.

Within a vinyl acetate reactor there may be as many as 6,000 or more reaction tubes containing catalyst. In a small percentage of those tubes, thermocouples may be placed to detect, determine and monitor temperatures within each of the selected reaction tubes. Shell and tube reactors vary in size and tubes may exceed 20 feet in length. Accordingly, multiple thermocouples, called multi-point thermocouples, may be placed in a given tube so that thermocouples are positioned inside the selected tube over its entire length.

Such multi-point thermocouples commonly include a series of thermocouples contained inside a thin-walled, small diameter stainless steel (or other suitable material) tube. In use, the stainless steel tube containing the multiple thermocouples is normally placed in the center of a reaction tube within the reactor and catalyst packed around the thermocouple tube in normal fashion. Each thermocouple tube is hardwired to a junction box outside the reactor which is then in turn hardwired to the control room so that the data generated from each thermocouple can be detected and stored in computer memory in the control room. In a commercial setting, the data can also be read out by operators in the control room.

The data generated by the thermocouples gives the operator valuable information regarding the operation of the process and the functioning of the reactor. Using multi-point thermocouples, the temperature of the reaction can be evaluated at multiple points or levels within that reaction tube. Thus, "hot spots" can be detected, within monitored tubes, and inferred for the others, so that appropriate action can be taken.

Even with this technology, because all reactor tubes cannot be monitored, and variations exist between flow and temperature conditions among tubes, "hot spots" can occur in the reactor and remain undetected. The conditions of the non-monitored tubes must be inferred from the monitored tubes. Furthermore, as the catalyst ages or as reaction rates are pushed by increasing the temperature of the reaction, the danger of thermal runaway increases. Accordingly, the need exists for a way to evaluate the temperature conditions within a shell and tube reactor in order to avoid thermal runaway conditions.

SUMMARY OF THE INVENTION

The method of the present invention is directed to evaluating a reaction within a shell and tube reactor for the signs of thermal runaway. The method of the present invention involves

restricting the flow of reactants through selected reaction tubes containing thermocouples in order to make these selected reactor tubes more susceptible to changes in reaction conditions and aging of the catalyst. These restricted flow thermocouple tubes will tend to register hotter than the remainder of the reaction tubes (due to the lower heat transfer coefficient which results from the lower velocity of the gases inside the tubes) in response to reaction condition changes and aging of the catalyst thus warning of the potential for thermal runaway.

In shell and tube reactors, the flow of reactants may be from the top to the bottom or bottom to top of the tubes (down flow or up flow respectively). Most convenient are downflow type tubes wherein the flow is from the top of the reactor tube to the bottom of the tube. Catalyst is typically loaded into the individual reactor tubes from the top of the tube. Accordingly, it is particularly convenient to restrict the flow of reactants to a given reactor tube from the top end of a reactor tube containing a thermocouple. The direction of flow and position of restrictor within the tube is irrelevant to this invention.

Flow may be restricted in one of these tubes by any number of means. One means is a restrictive orifice insert positioned in the inlet or top of a down flow reactor tube. The restrictive orifice would be configured so as to reduce reactant flow generally by approximately 10%. Another means for restricting flow in a thermocouple tube is to use a smaller inert support in the upper portion of the reaction tube. For example, where a catalyst is loaded on 7 mm diameter support particles, 5 mm inert particles would be used above the 7 mm catalyst support. This matrix of inert particles would restrict the flow of reactants through that reactor tube.

In accordance with one aspect of the invention, a method for evaluating a reaction within a shell and tube reactor for signs of thermal runaway is provided. The method includes the steps of equipping a plurality of reactor tubes with a thermocouple; restricting the flow of reactants through selected reactor tubes which contain a thermocouple; operating the process at desired reaction conditions; determining a temperature profile for each reactor tube containing a thermocouple; comparing the differences between the temperature profiles for the reactor tubes into which the flow of reactants is restricted and the temperature profiles for the reactor tubes into which the flow of reactants is not restricted; and correlating the differences between the temperature profiles with signs of thermal runaway. The reaction conditions could then be adjusted in response to signs of thermal runaway.

In accordance with another aspect of the invention, an apparatus for restricting the flow of reactants into a reactor tube within a tube and shell reactor is provided. The apparatus is a

restrictive flow insert configured to be positionable in an end of the reactor tube within the shell and tube reactor. The restrictive flow insert is designed to reduce the flow of reactants into the tube by a predetermined amount, for example, by about 10-15%.

In accordance with another aspect of the invention, a means for restricting the flow of reactants into a reactor tube within a tube and shell reactor is provided. The flow restricting means is positionable within the reactor tube within the shell and tube reactor and is configured to reduce the flow of reactants through the reactor tube by a predetermined amount, for example, by about 10-15%. Numerous flow restricting means are possible. For example, the means could be configured as a reactor tube entrance or exit diameter reduction device such as a restrictive orifice insertable in the reaction tube; the inside diameter of a portion of a particular reactor tube could be reduced by some predetermined amount using a diameter reducing insert; the use of a smaller diameter catalyst support loaded into the reactor tube above, or below, the catalyst charge; and the like. A reactor tube could likewise be constricted during design and have a restriction built-in to the tube.

In accordance with another aspect of the invention, a shell and tube reactor is provided. The reactor includes a reactor shell; a plurality of reactor tubes positioned spaced apart within the reactor shell; a first tube sheet affixing the reactor tubes at a first end thereof; a second tube sheet affixing the reactor tubes at a second end thereof; a plurality of multi-point thermocouples wherein a single multi-point thermocouple is positioned within a single reactor tube in a selected number of reactor tubes; and a plurality of means for restricting the flow of reactants through a reactor tube wherein a flow restricting means is positioned in at least one of the reactor tubes equipped with a multi-point thermocouple.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic illustration of a vapor-phase process for producing vinyl acetate.

Fig. 2 is a side view of a partial breakaway of a shell and tube reactor.

Fig. 3 is a top view of a cross section of the reactor illustrated in Fig. 2.

Fig. 4 is a close up view of a segment of Fig. 3.

Fig. 5 is a side view of a cross section of several of the reactor tubes illustrated in Fig. 4.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Although the present invention will be described relative to production of VA, it is understood to be generally applicable to reactions involving use of shell and tube reactors. Figure 1 illustrates diagrammatically a very simplified vapor-phase process for producing vinyl acetate. Vinyl acetate is produced in the vapor-phase from reactants ethylene, acetic acid, and oxygen which are passed over a catalyst which typically contains palladium. The catalyst is typically supported on some form of an inert support which is typically in the form of pellets of various shapes and sizes. The supports are typically spherical in nature.

Referring to Fig. 1, the supported catalyst would be loaded into a shell and tube reactor 10. Ethylene enters the reactor loop 20 from line 30, where it mixes with recycled gases from compressor 100. The acetic acid enters the acetic acid vaporizer 40 through line 50 where it is mixed with the resultant ethylene enriched recycle gas and vaporized. The recycle gas/acetic acid mixture in the vapor-phase pass through the vaporizer overhead 60 toward the reactor 10. Oxygen enters the reactor loop 20 and vaporizer overhead 60 through line 65. Ethylene, acetic acid, and oxygen along with other components of the recycle gas are all passed into reactor 10.

Inside shell and tube reactor 10, the reactants, ethylene, acetic acid, oxygen, and other gaseous components are passed through reactor tubes over the supported catalyst under conditions favorable for reaction. Vinyl acetate, unreacted ethylene, acetic acid, and oxygen all pass out of reactor 10 into product recovery section 70. In the product recovery section 70 crude vinyl acetate is separated out from the reactants and sent on to purification by way of line 80. The gaseous components (e.g., N_2, Ar, O_2, CO_2, CH_4, $C_2^{=}$) pass through line 90 to the recycle gas compressor 100 where they are then returned to the acetic acid vaporizer 40.

Fig. 2 illustrates a shell and tube reactor represented as reactor 10 in Fig. 1. Shell and tube reactor 10 includes a reactor shell 110 encompassing a plurality of reactor tubes 120. The reactor tubes 120 are supported at their top and bottom ends by tube sheets 130. In Fig. 2, only the upper tube sheet 130 is shown. The reactor tubes 120 are spaced apart such that, as seen in Figure 2, there is space 135 between each and every reactor tube 120. The space 135 is for water to be circulated between and amongst the reactor tubes 120 for heat exchange and dissipation.

As seen in Figure 2, there is head space 140 above tube sheet 130 and the openings into the reactor tubes 120. The reactants, ethylene, acetic acid, and oxygen enter the top portion of reactor 10 into head space 140 under pressure. The reactants are then forced through the reactor tubes 120 which contain the catalyst for the production of vinyl acetate.

As can be seen in Figure 2, there may be a large number of reactor tubes 120 within a shell and tube reactor 10. Indeed, the number of reactor tubes 120 within a shell and tube reactor 10 may exceed 6,000. With so many reactor tubes 120 within a shell and tube reactor 10, operators of such vapor-phase processes as a vinyl acetate production process will seek to determine the temperature of reaction within selected reactor tubes 120.

Referring now to Fig. 3, selected reactor tubes 120 contain thermocouples 150 positioned inside them. These thermocouples 150 are positioned centrally within the reactor tubes 120 and the supported catalyst for the vapor-phase reaction loaded around the thermocouple 150. Thermocouples 150 may be single point thermocouples so that they measure temperature at a specific point or they may be multi-point thermocouples such that a series of individual thermocouples is positioned along the entire length of a reactor tube 120. Multi-point thermocouples are typically a series of thermocouples positioned within a small diameter tube. The tube containing the thermocouples may be a thin-walled stainless steel and it is positioned in the center of a reactor tube 120 and the supported catalyst loaded around the multi-point thermocouple tube in the usual manner.

Multi-point thermocouples typically extend the entire length of the reactor tube 120 and are hard-wired to a junction box outside of the reactor, which is in turn hard-wired to the reaction control room where the data gathered from the various thermocouples may be assessed and stored.

Reactor tubes 120 may exceed 20 feet in length. Thus, using a multi-point thermocouple, temperature evaluations can be made of the reaction at various points or levels within the reactor. Such data gives a more complete picture of the reaction conditions in the shell and tube reactor 10 with respect to temperature.

It has been learned that reactor tubes which exhibit a restricted flow of reactants will tend to operate at a higher temperature than surrounding unrestricted reactor tubes. Furthermore, it has been learned that with respect to the vapor-phased production of vinyl acetate, that reactor tubes containing a multi-point thermocouple and having a restricted flow of reactants will tend to operate at temperatures within normal limits of the other reactor tubes containing thermocouples during typical operating conditions. However, under certain reaction conditions, particularly when reaction rates are increased or as the catalyst ages, these restricted flow tubes tend to flare up or run hotter than the unrestricted tubes. These flare-ups tend to indicate that the reaction may be reaching thermal runaway conditions.

It is also been found that when reaction conditions are adjusted in response to these flare ups, e.g., reduction of reaction rates, the temperature profiles of the restricted flow tubes return to within

acceptable limits of the temperature profiles for the reactor tubes to which the flow reactants remains unrestricted. Accordingly, it has been learned that restricting the flow of reactants to even a single thermocouple tube in a shell and tube reactor can serve as a way to detect thermal runaway conditions before the rest of the reactor reaches those conditions.

The amount of restriction used will be determined by the reaction, the operator, the reactor, and the safety margin necessary for a given reaction. Those skilled in the art will recognize that this variable is one of choice. For example, it is anticipated that a restriction of from about 10-15% would be appropriate. The amount of restriction should be sufficient to cause tubes being restricted to develop "hot spots" before or instead of the non-restricted tubes. "Before" here refers to a period of time wherein as the process conditions change, the restricted tubes will exhibit "hot spots" before, or instead of, the non-restricted thermocouple tubes.

The flow of reactants into a reactor tube may be restricted in any number of ways. Typically, reactor tubes 120 are open at each end. Accordingly, the flow of reactants may be restricted at either the inlet end or the outlet end. Reactor tubes 120 are generally loaded with catalyst from the top. Referring to Figure 2, reactor tubes 120 would be loaded from the head space 140, or inlet end, of reactor tubes 120. Thus, for convenience sake, it would be easier to place a flow restricting means in the inlet end of reactor tubes 120.

There are numerous means for restricting the flow of reactants through reactor tubes 120. For example, during the loading of the catalyst in the thermocouple containing reactor tube 120 a smaller diameter support material may be substituted for the supported catalyst in the last several feet nearest the inlet end of reactor tube 120. For example a 7 mm diameter support with catalyst on its surface would be loaded into the reactor tube 120 up to within several feet of the inlet end of reactor tube 120. The last several feet of reactor tube 120 would be loaded with a 5 mm diameter support either with or without catalyst on it and the flow of reactants through reactor tube 120 would be reduced. The amount of flow reduction could be measured and adjustments made until reaching the desired amount.

Devices which would change either the inlet or the outlet diameter of reactor tube 120 could also serve to restrict the flow of reactants through reactor tube 120. Such a device could be configured as an insert positionable within the inside diameter of reactor tube 120. The insert would include an restricted orifice. The diameter of the orifice could be engineered to achieve a desired flow reduction.

Other means which could acceptably reduce the flow of reactants into reactor tube 120 would

be the use of a membrane or other screening type device placed at either the inlet or outlet end of reactor tube 120. Importantly, all flow reduction means should be made of a corrosion resistant material, including certain special metallurgies which may be necessary to resist particularly corrosive chemicals used in these processes.

While the flow of reactants may be restricted into any given reactor tube 120 due to polymer formation within a reaction tube, variation in the loading of the catalyst, a high percentage of fines in the loaded catalyst, and the like, the method of the present invention recognizes that the reduction of flow of reactants must be in the reactor tubes 120 in which thermocouples 150 have been placed and that the reduction in flow of reactants be some known amount. Accordingly, means which may be engineered to predictably produce the desired flow of reactants into reactor tube 120 would require less difficulty in placement and calibration for the purposes of the method of the present invention.

Referring again to Figure 3, interspersed among reactor tubes 120 are reactor tubes containing thermocouples 150 and reactor tubes 120 containing both thermocouples 150 and flow restricting devices 160.

Figure 4 better illustrates the presence of the three separately configured reactor tubes 120. An embodiment of the apparatus of the present invention as illustrated in Figure 4 is that of an insert positioned in the opening of reactor tube 120. The insert 160 is configured to fit securely in the inlet opening of reactor tube 120. Insert 160 may be positioned within reactor tube 120 using a frictional fit, it may be threaded with the reactor tube having reciprocal threading, it may be secured using an additional resilient member disposed about the circumference of the insert so that there is a frictional engagement of the inner diameter of reactor tube 120, and the like. Alternatively, the insert 160 may be permanently secured such as by welding onto the tube. A further alternate may be a restricting means such as a washer or washer-like device which is placed above the catalyst bed, within or on top of the inert materials. The washer does not necessarily have to be secured permanently or fit securely within the tube. It may also have a single hole or multiple holes, provided that the object of flow restriction is achieved. Those skilled in the art will be aware of and appreciate numerous ways of securing or designing insert 160 within the inner diameter of reactor tube 120.

Referring to Figure 5, the three different configurations of reactor tubes 120 can be seen in cross-section. Reactor tubes 120 are spaced apart and fixed in position by tube sheet 130 both at the inlet and outlet ends of reactor tubes 120. The arrows present just above each of the illustrated reactor tubes 120 indicates their inlet end.

Flow restricting insert 160 is positioned in the end of reactor tube 120. Insert 160 is configured in the form of an insert possessing a channel running through the plug and having an orifice at either end of the channel. The diameter of channel 170 in insert 160 may be designed and engineered to provide a predetermined reduction in the flow of reactants into reactor tube 120.

EXAMPLES

Reactor tubes were monitored during production of VA. Several tubes with thermocouples contained restricted flow. Below are graphs showing temperature fluctuations of the restricted and non-restricted flow tubes.

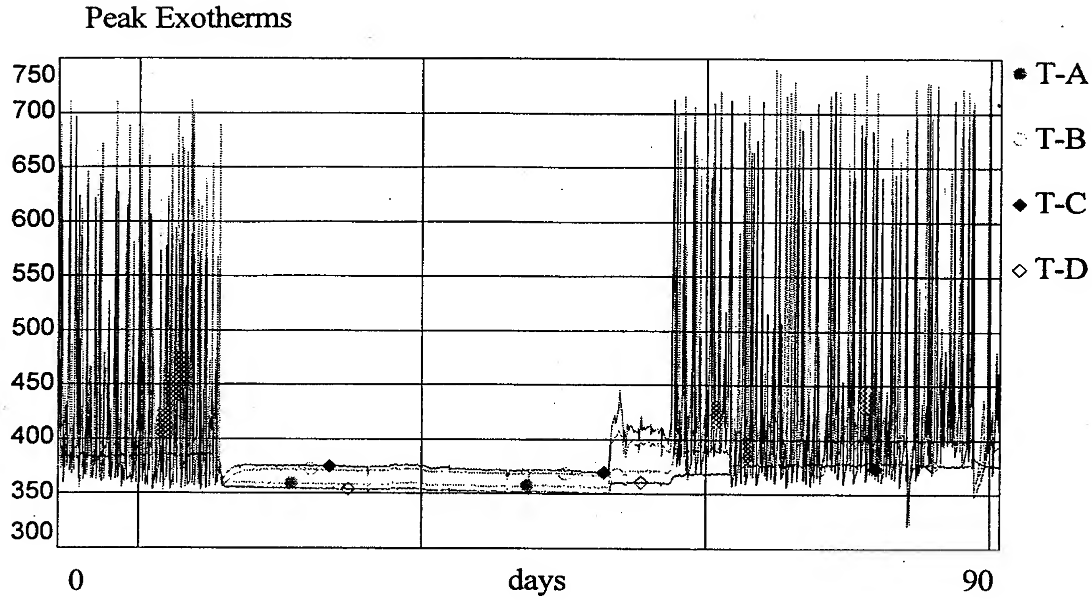
Eight tubes with thermocouples were monitored over the course of about 90 days. Three of the tubes became partially restricted during upset in operation conditions by inadvertent carry-over of unknown materials during the VA process. The tubes were about 20 feet in length, with the thermocouple placed about 11 feet from bottom of the tube. VA catalyst having about 7 mm diameter was packed around the tube.

Table 1 illustrates oxygen feed rate (lb/hr) fluctuations in restricted and non-restricted thermocouple tubes over about a 90 day period.

TABLE 1

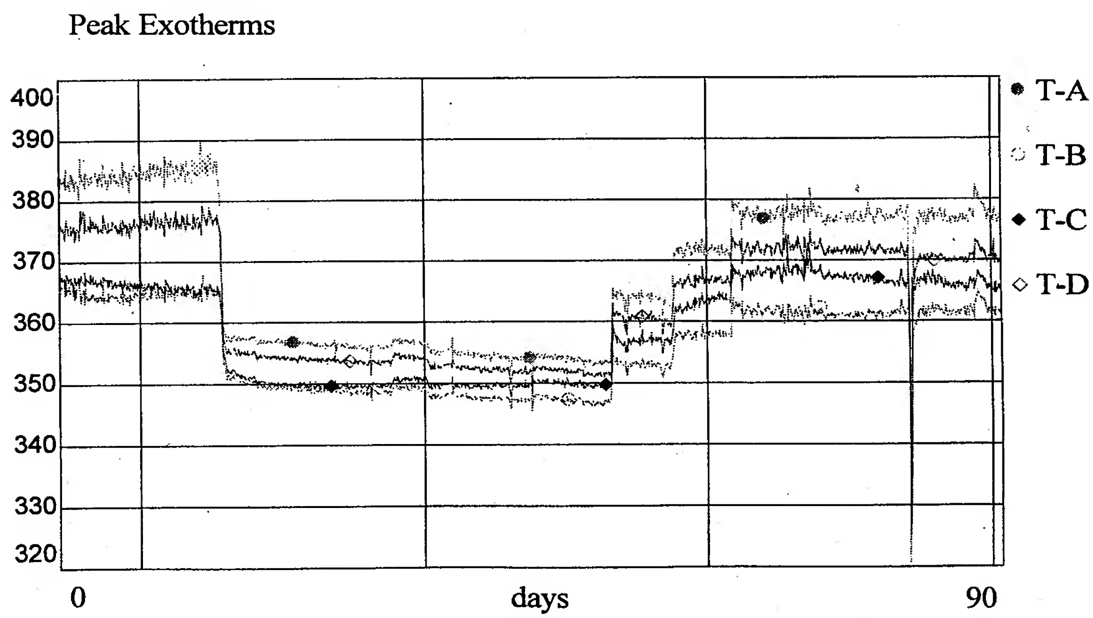
Days	O_2 Feed Rate (lb/hr)
0-15	20,000
16-43	12,000
44-50	15,000
51-55	17,500
56-90	19,000

Restricted Flow Tubes



T = Thermocouple

Non-Restricted Flow Tubes



T = Thermocouple

As can be seen from the graphs, the non-restricted tubes produced peak exotherm temperatures of between 365-385 °C while the restricted flow tubes produced peak exotherm temperatures in the range of about 350 °C to about 700 °C over the same monitoring period.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

CLAIMS

What is claimed is:

1. A method of evaluating a reaction within a shell and tube reactor for signs of thermal runaway comprising the steps of:

equipping a plurality of reactor tubes with a thermocouple, the reactor tubes being adapted so that reactants can flow through them;

restricting the flow of reactants through selected reactor tubes which contain a thermocouple;

operating the process at desired reaction conditions;

determining a temperature profile for each reactor tube containing a thermocouple;

comparing the differences between the temperature profiles for the reactor tubes into which the flow of reactants is restricted and the temperature profiles for the reactor tubes into which the flow of reactants is not restricted; and

correlating the differences between the temperature profiles with signs of thermal runaway.

2. The method of claim 1 further comprising the steps of:

adjusting the reaction conditions in response to signs of thermal runaway.

3. The method of claim 1 further comprising the steps of:

evaluating the differences between the temperature profiles for the reactor tubes into which the flow of reactants is restricted and the temperature profiles for the reactor tubes into which the flow of reactants is not restricted with respect to the reaction conditions; and

adjusting the reaction conditions in response to the differences in temperature profiles.

4. The method of claim 1 wherein each of the thermocouples is a multi-point thermocouple.

5. The method of claim 1 wherein at least one of the thermocouples is a multi-point thermocouple.

6. A method of evaluating a reaction within a shell and tube reactor for signs of thermal runaway comprising the steps of:

equipping a plurality of reactor tubes with a multi-point thermocouple, the reactor tubes being adapted so that reactants can flow through them;

providing a means for restricting the flow of reactants through a reactor tube;

positioning the means for restricting the flow of reactants in at least one of the reactor tubes containing a multi-point thermocouple;

operating the process at desired reaction conditions;

determining a temperature profile for each reactor tube containing a multi-point thermocouple;

comparing the temperature profiles for the reactor tubes into which the flow of reactants is restricted with the temperature profiles for the reactor tubes into which the flow of reactants is not restricted; and

correlating the differences between the temperature profiles with the signs of thermal runaway.

7. The method of claim 6 further comprising the step of:

adjusting the reaction conditions in response to the signs of thermal runaway.

8. The method of claim 6 further comprising the steps of:

evaluating the differences between the temperature profiles for the reactor tubes into which the flow of reactants is restricted and the temperature profiles for the reactor tubes into which the flow of reactants is not restricted with respect to the reaction conditions; and

adjusting the reaction conditions in response to the differences in temperature profiles.

9. An apparatus for restricting the flow of reactants into a reactor tube within a shell and tube reactor comprising:

an insert adapted to be positionable in an end of the reactor tube within the shell and tube reactor, the insert being configured to reduce the flow of reactants into the tube by a predetermined amount.

10. The apparatus of claims 9 wherein the flow of reactants into the reactor tube is reduced by about 10%.

11. The apparatus of claim 9 wherein the flow of reactants into the reactor tube is reduced by about 10%.

12. The apparatus of claim 9 wherein the insert is cylindrically shaped, the insert having a first end and a second end and having a centrally positioned channel running from the first end to the second end, the channel terminating in an orifice at each end of the channel.

13. The apparatus of claim 12 wherein the flow of reactants into the reactor tube is reduced by about 10%.

14. The apparatus of claim 12 wherein the flow of reactants into the reactor tube is reduced by about 15%.

15. An apparatus for restricting the flow of reactants into a reactor tube within a shell and tube reactor comprising:

a flow reducing means positionable within the reactor tube within the shell and tube reactor, the flow reducing means configured to reduce the flow of reactants to the reactor tube by a predetermined amount.

16. An apparatus of claim 15 wherein the flow of reactants into the tube is reduced 10%.

17. An apparatus of claim 15 wherein the flow of reactants into the tube is reduced 15%.

18. A shell and tube reactor comprising:

a reactor shroud;

a plurality of reactor tubes positioned spaced apart within the reactor shroud, the reactor tubes being adapted to receive a flow of reactants through them;

a first tube sheet affixing the reactor tubes at a first end thereof;

a second tube sheet affixing the reactor tubes at a second end thereof;

a plurality of multi-point thermocouples, a single multi-point thermocouple being positionable within a single reactor tube, each of the plurality of multi-point thermocouples being

positioned in each of a plurality of selected reactor tubes; and

a plurality of means for restricting the flow of reactants through a reactor tube, the flow restricting means being positioned in at least one of the reactor tubes equipped with multi-point thermocouples.

19. The shell and tube reactor of claim 18 wherein the flow restricting means comprises:

an insert adapted to be positionable in an end of the reactor tube within the shell and tube reactor, the insert being configured to reduce the flow of reactants into the tube by a predetermined amount.

20. The shell and tube reactor of claim 19 wherein the flow restricting means reduces the flow of reactants into the reactor tube by about 5%.

21. The shell and tube reactor of claim 19 wherein the flow restricting means reduces the flow of reactants into the reactor tube by about 10%.

22. The shell and tube reactor of claim 19 wherein the flow restricting means is a plug cylindrically shaped, the plug having a first end and a second end and having a centrally positioned channel running from the first end to the second end, the channel terminating in an orifice at each end of the channel.

23. The shell and tube reactor of claim 22 wherein the flow restricting means reduces the flow of reactants into the reactor tube by about 5%.

24. The shell and tube reactor of claim 22 wherein the flow restricting means reduces the flow of reactants into the reactor tube by about 10%.

FIG. 1

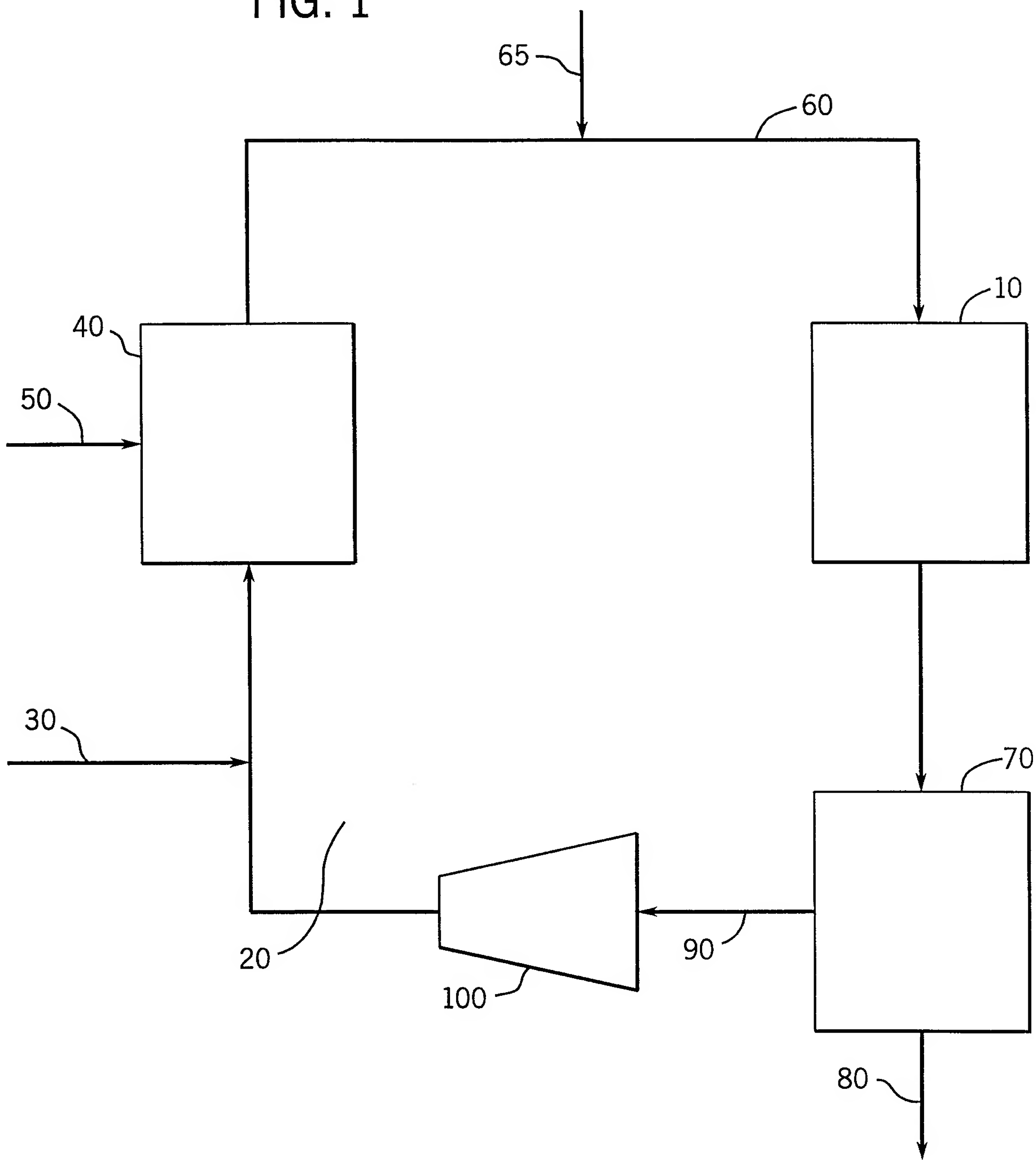


FIG. 2

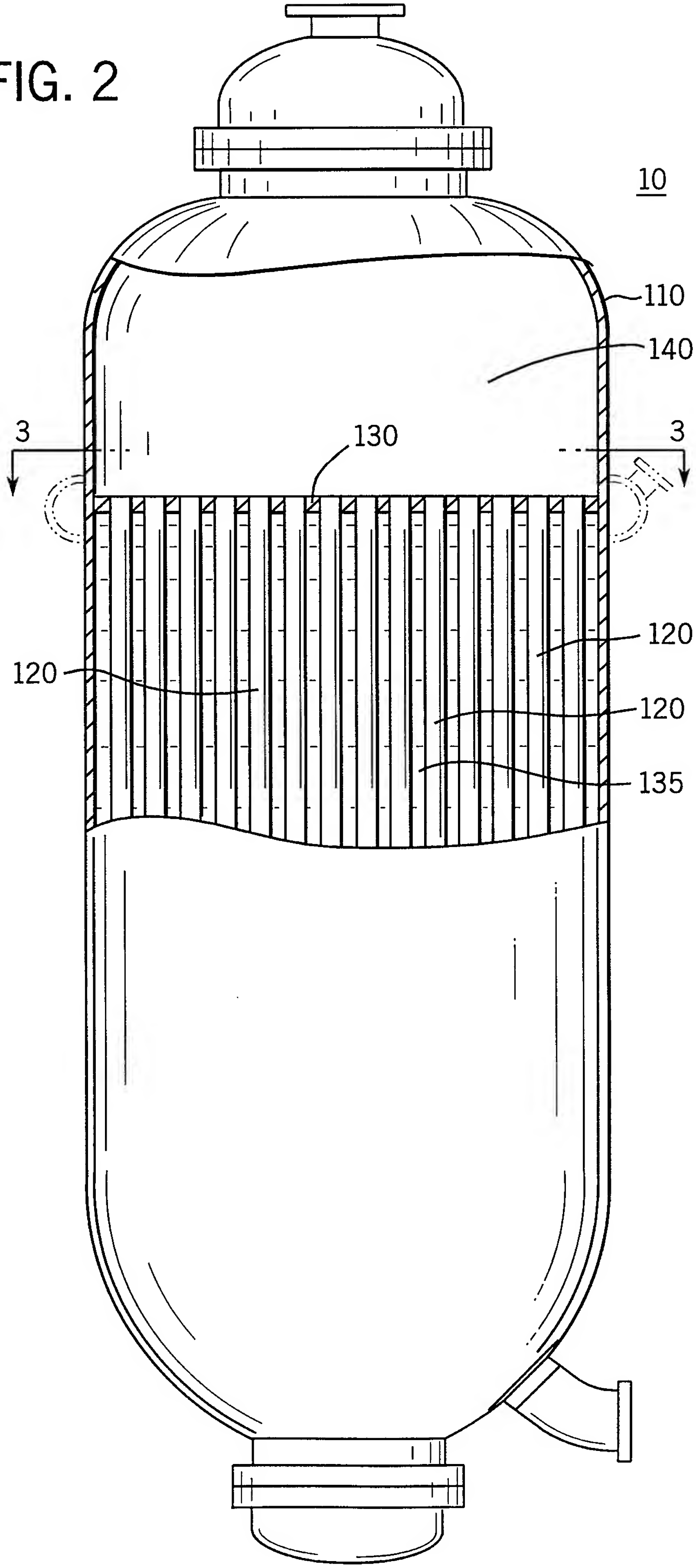
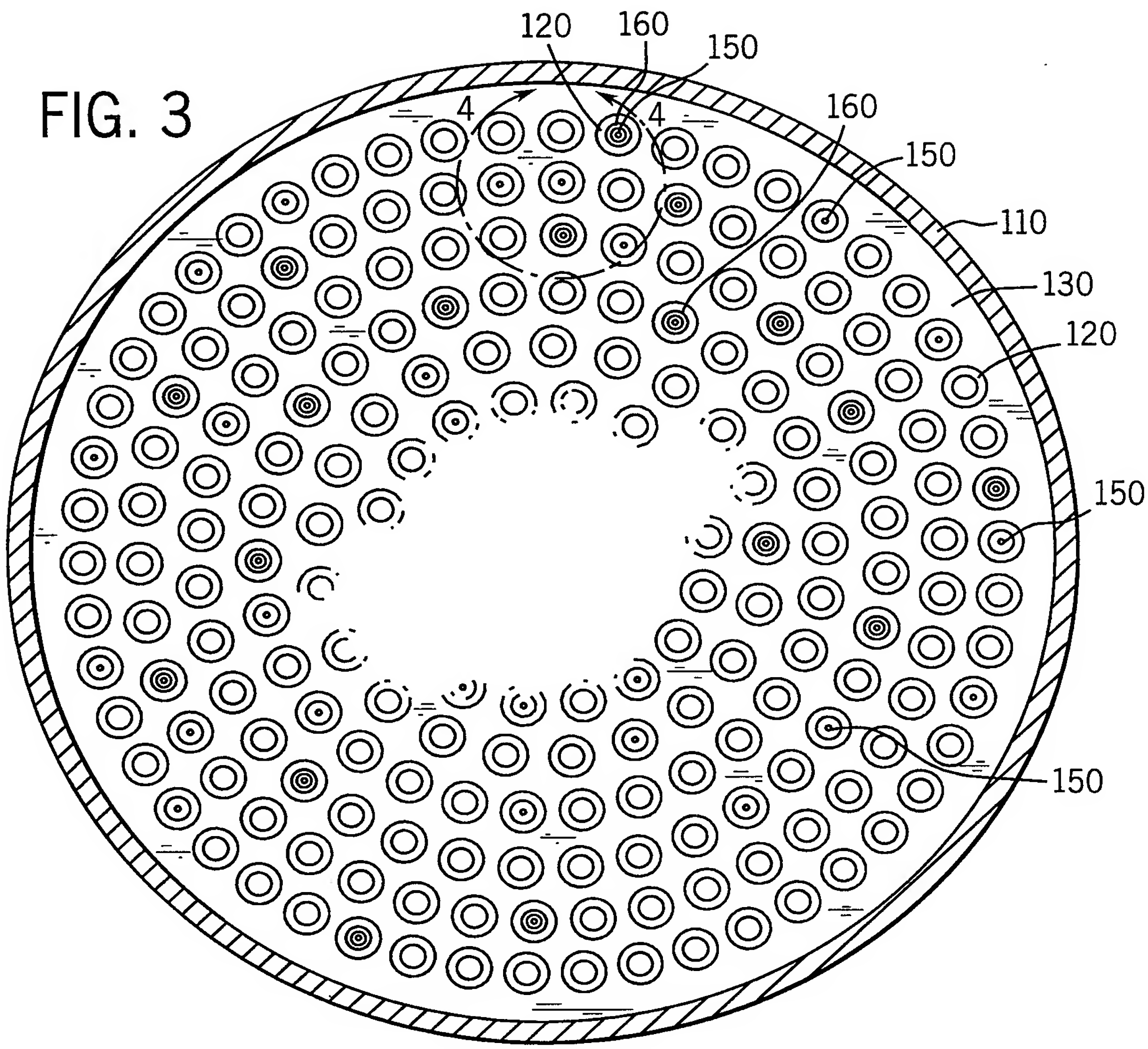
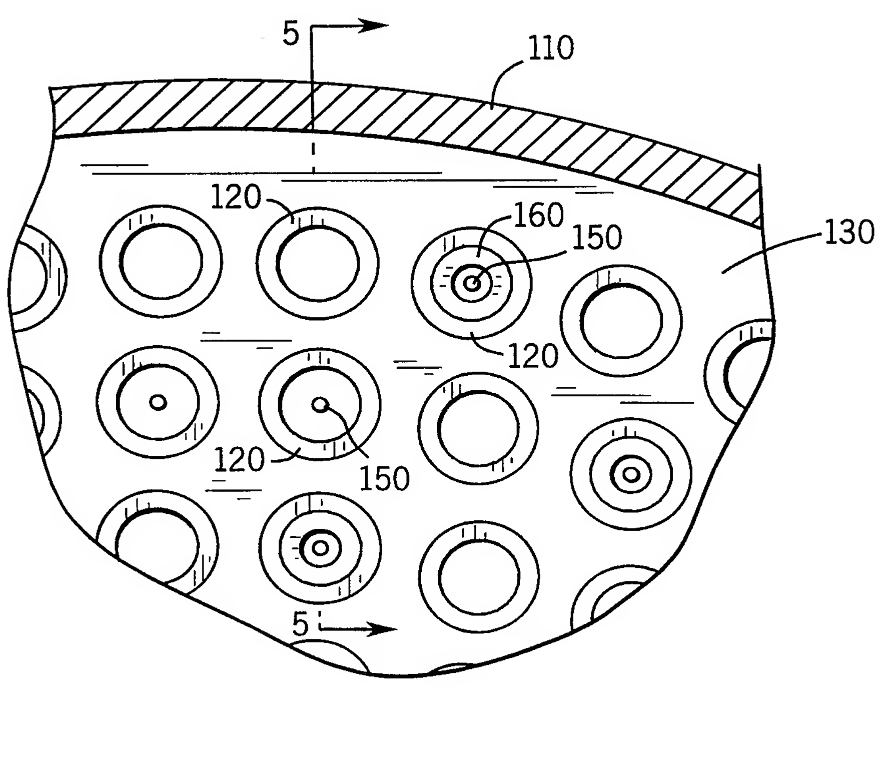


FIG. 3



120
160
150
4
4
160
150
110
130
120
150
150

FIG. 4



5
110
120
160
150
130
120
120
150
5

FIG. 5